A METHOD OF DFTERMINING THE RELATIVE AMOUNTS OF D-AND E-REGION ABSORPTIONS OF MEDIUM AND SHORT RADIO WAVES

By A. P. MITRA

Radio Research Committee, N.P.L. Bldgs. New Delhi-12

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ABSTRACT. A new method is developed by which the relative amounts of D and E-region absorptions in any medium and short wave observation may be determined purely on physical basis. The method utilizes the concept of 'relaxation time' in ionospheric levels and rests on the fact that the 'relaxation time' at the D-region levels is appreciably different from that at the E-region levels.

1. INTRODUCTION

One of the most difficult problems in the interpretation of absorption of medium and short waves is to determine how much of the measured absorption is due to the D-region and how much due to the E-region. In perhaps the most carefully conducted series of experiments on absorption, Appleton and Piggott (1954) took particular care to use frequencies at which P'-f curve did not show any appreciable group retardation. Although the resultant absorption showed little scatter when plotted against the square of the effective frequency, some absorption may yet have remained. In measurements where no particular care is taken to eliminate the E-absorption, the question is still more important. The purpose of this note is to present a method by which the relative amounts of D and E-region absorptions of medium and short radio waves may be determined.

2. DEVELOPMENT OF THE METHOD

In any effort to separate the two contributions, one must concentrate on the physical parameters that are different in two regions and that are easy to measure. One such parameter is what is sometimes known as the 'sluggishness' of the ionosphere, which arises due to the finite recombination time in the ionization at the relevant level. This sluggishness may be measured by the delay in the time of the maximum of the ionization at any level from the time of the local noon. This delay is also known as the 'relaxation time,. Now the relaxation time $\tau(h)$ at any height h is given by (Mitra and Jones, 1953; Appleton, 1953).

$$\tau(h) \approx \frac{1}{2\alpha(h)N(h)}$$

where $\alpha(h)$ and $N(h)$ are the values of the effective recombination coefficient at any height h. Since α and N are different at D- and E-region levels, τ_D will be different from τ_E. That this is so, has been confirmed by the results of analysis of various radio propagation data made by a number of authors. Thus, analysis of the day time observations on absorption and polarization of 150Kc/s radio waves, which must refer to the D-region only, has yielded a value of about 60 minutes (Mitra and Jones, 1954). On the other hand, analysis of the diurnal variation of *of E* in Washington, yielded a relaxation time of about 4 minutes. This very large difference in the values of τ_D and τ_E provides a sensitive method for determining the relative amounts of D and E absorptions in any measurement where both absorptions exist.

If one ignores the delay in the maximum of the ionization, the diurnal variations of the D- and E-region absorptions, denoted by A_D and A_E respectively, may be written as:

$$A_D = A_{D0} \cos^n \chi$$
$$A_E = A_{E0} \cos^p \chi$$

where the zero suffixes indicate corresponding values for $\chi = 0°$, and n and p are constants. In terms of hour angle ϕ, these equations become:

$$A_{D_0} = A_{D_0}[\sin \delta \cos \theta + \cos \delta \sin \theta \cos \phi]^n$$
$$A_{E_0} = A_{E_0}[\sin \delta \cos \theta + \cos \delta \sin \theta \cos \phi]^p$$

where δ is the declination of the sun and θ is the colatitude of the station.

The corresponding equations, when the maximum is delayed, are:

$$A_D = A_{D0}[\sin\delta \cos\theta + \cos\delta \sin\theta \cos(\phi - \phi_1)]^n$$
$$A_E = A_{E0}[\sin\delta \cos\theta + \cos \delta \sin \theta \cos(\phi - \phi_2)]^p$$

where ϕ_1 and ϕ_2 are the values of the hour angles at which A_D and A_E attain their maximum values.

The resultant absorption $(A_D + A_E)$ will then attain its maximum at a time $\bar{\phi}$ given by

$$\bar{\phi} \simeq \frac{n\bar{A}_D\phi_1 + p\bar{A}_E\phi_2}{n\bar{A}_D + p\bar{A}_E}$$

provided the ϕ's are small or, when expressed in relaxation times,

$$\bar{\tau} \simeq \frac{n\bar{A}_D\tau_D + p\bar{A}_E\tau_E}{n\bar{A}_D + p\bar{A}_E} \quad .. \quad (1)$$

where $\bar{A}_D$ and $\bar{A}_E$ denote the values of A_D and A_E at the time of maximum resultant absorption. Eqn. (1) which may also be written as

$$\frac{p\bar{A}_E}{n\bar{A}_D} \simeq \frac{\tau_D - \bar{\tau}}{\bar{\tau} - \tau_E}$$

gives the necessary mathematical expression for determining the relative amounts of D- and E-region absorption of medium and short waves. The diurnal variation of the measured absorption provides the value of $\bar{\tau}$. Then if τ_D and τ_E are known then $(p\bar{A}_E/n\bar{A}_D)$ which is (p/n) times the ratio of the E- and D-region absorption values, may be computed.

Probable values of τ_D and τ_E have already been mentioned. Of these τ_E is perhaps better known than τ_D. The value of the former is small, of the order of 4 minutes, and shows little latitudinal variation. Eclipse observations on *foE* also indicate a relaxation time of this order. Further, one may compute τ_E from the value of α_E obtained otherwise and from the E-region electron density. Since α_E is of the order of 10^{-8} cm^3/sec., and $N_E \sim 10^5$/cm^3, the value of τ_E thus computed comes to about 8 minutes. A typical value of τ_E will be about 5 minutes.

Values of τ_D have been reported in a paper by Mitra and Jones (1953). Measurements on absorption at 150Kc/s by Benner (1951) showed a relaxation time of 60 minutes and those of polarisation at the same frequency by Nearhoof (1951) gave 80 minutes. Detailed examination of the variation of the equivalent height of reflexion at 50Kc/s, original records of which were kindly supplied to the author by Dr. Watts of the National Bureau of Standards, showed a relaxation time of about 60 minutes for an equivalent height around 85 Km. It seems reasonable to conclude that τ_D is not much different from 60 minutes.

The values of p and n are uncertain, but some idea may be formed from theoretical arguments as also from various experimental determination of the cos χ-exponents, obtained from absorption measurements. At 150Kc/s for which the day time absorption is due predominantly to the D-region, the exponent has a value of 0.62 in the morning and 0.42 in the afternoon (Benner, 1951). At higher frequencies the values are larger. The average value given by Appleton and Piggott (1954) for medium radio waves is 0.75, but values ranging anywhere between 0.5 and 1.5 have been reported. Critical examination of these various results appears to indicate that the larger values are almost always associated with increased contamination by the E-region absorption, and, in the extreme case, where the E-region absorption predominates, the exponent has a value around 1.5. It appears, therefore, that the value of n is somewhere around 0.6 and that of p around 1.5.

Theoretical arguments also give similar values. At the levels which contribute most to the D-region absorption ($\sim$80 Km.) the collision frequency is fairly large, having a value of about 5×10^6/s. For a Chapman-type electron distribution of the D-region, the theoretical value of n would then be about 1.1, while for the (more realistic) case where recombination coefficient varies directly with pressure, the value would be about 0.65 (Appleton and Piggot, 1954). A. P. Mitra (1954) has recently given a theoretical model for the D-region electron distribution which appears to fit with both long wave and short wave experimental results. This model has since been revised in the light of SID observations (Mitra, unpublished). The value of the exponent n for the revised model comes out to be 0.62.

In view of the above, it seems reasonable to accept a ratio of about 2.5 for (p/n) with a probable range between 2 to 3.

In the measurements of Appleton and Piggot, the observed relaxation time was about 30 minutes. For the values given above, such a relaxation time would indicate an E-region contribution of between 1/3 to 1/2 of the D-region absorption for the relevant measurements.

It may also be mentioned that the exponent K should provide an additional confirmation of the value of the ratio determined by the above method, since K is given by

$$K = \frac{n\bar{A}_D + p\bar{A}_E}{\bar{A}_D + \bar{A}_E}.$$

For $n = 0.6$, $p = 1.5$, $k = 0.75$, $\bar{A}_E/\bar{A}_D$ is about 1/5.

In conclusion, it may be pointed that Eq. (1) should also be useful in studying the location of the fadeout absorption, and, in general, wherever two or more regions having different relaxation times are involved.

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